Wisconsin Highway Research Program

Base Compaction Specification Feasibility Analysis

Wisconsin Highway Research Program
LIMITED USE DOCUMENT

The Board of Regents of the University of Wisconsin System
University of Wisconsin-Milwaukee
Graduate School-Research Services and Administration
P.O. Box 340
Milwaukee, Wisconsin 53201

March 3, 2010

Summary Page

Project Title: Base Compaction Specification Feasibility Analysis

Proposing Agency: The Board of Regents of the University of Wisconsin System
University of Wisconsin-Milwaukee
Graduate School-Research Services and Administration
P.O. Box 340
Milwaukee, Wisconsin 53201

Person Submitting the Proposal: Hani H. Titi, Ph.D., P.E.

Proposal Written By: Hani H. Titi, Ph.D., P.E.

Proposal Date: March 3, 2010

Principal Investigator: Hani H. Titi, Ph.D., P.E.
Associate Professor
Department of Civil Eng. and Mechanics
University of Wisconsin-Milwaukee
P.O. Box 784
Milwaukee, WI 53201
hanititi@uwm.edu
(414) 229-6893

Administrative Officer: Peggy Vanco
Director
Research Services and Administration
Mitchell Hall, Room 273
Milwaukee, WI 53201
(414) 229-4853
pvanco@uwm.edu

Proposed Contract Period: 15 months

Total Contract Amount: $91,993

Indirect Cost Portion at: 15%

Table of Content

Research Plan

a. Background

Problem Statement:

For approximately the last fifteen years WisDOT construction specifications have been transitioning from "method" specifications to "performance" specifications. WisDOT's Base Aggregates specifications are a set of specifications that have not yet made that transition. These specifications rely on construction method terms such as "Standard Compaction" to provide contractors and department construction managers and inspectors with the necessary guidance and acceptance measures to construct good performing quality aggregate bases. Review of the "Standard Compaction" description reveals the use of ambiguous and rather subjective terminology such as "appreciable displacement." WisDOT SS 301 also uses terms such as "soft" and "spongy" in identifying adequate foundation preparation prior to base aggregate placement. This leads to accepted base layers that exhibit variable stiffness values that contribute to HMA pavement performance issues.

Flexible pavement design includes unbound granular layers (as defined by WisDOT SS 305) as part of the overall pavement structure. Pavement designers would be able to increase a pavement design's cost effectiveness if a pavement material's engineering properties are more consistent and correlated to specification performance criteria. A base aggregate specification that is based on performance criteria for compaction will improve pavement structural designs and also reduce construction costs and delays arising from base failures during construction.

Many other SHAs are using performance based specifications for base aggregates, what is the feasibility for WisDOT to transition to this type of specification in order to realize better cost savings related to HMA expenditures and resultant pavement performance?

Research Objective

The objective of this proposed research is to establish the technical engineering and cost analysis that will allow WisDOT Management to objectively evaluate the feasibility of switching specification philosophies for base aggregate materials. The proposed research will also provide technical recommendations for a proposed performance based base aggregate specification. The proposed performance based specification should utilize performance criteria in terms of a minimum and uniform stiffness measurement parameter consistent with modern technology and Mechanistic Empirical Pavement Design Guide (MEPDG) pavement design input parameters. Furthermore, these criteria should be consistent with other pavement layer performance based specifications.

Background

According to the Wisconsin DOT Standard Specifications 301 (WisDOT SS.301), the compaction of base aggregate should take place until "no appreciable displacement, either laterally or longitudinally, under the compaction equipment". Then it mentions that "if the material is too dry to readily attain the required compaction, add water as necessary to achieve compaction". Only when "special compaction" is required, the specification requires a quantifiable measure to assess the quality of the compacted layer. In this case, the specifications require a compacted density more than 95% of maximum dry density.

It is clear that there is a dire need for a performance based procedure that defines acceptable base compaction for building durable roads. Designing granular layers for flexible pavement, through WisDOT SS.305, references SS.301. In addition, it specifies the maximum layer thickness based on the aggregate nominal maximum aggregate size. Furthermore, in case of encountering soft spots in the base course; the specifications permit the engineer to request excavation below the subgrade. However, the specifications do not provide acceptance limits for these spots. Most of the decisions regarding the appropriate compaction, the remedial of the soft spots are left to the engineer's judgment. Developing a performance

based specifications will provide the engineer with a much needed tool to arrive to the most appropriate decision practically, and economically.

Recently, in a project funded by WHRP the load carrying capacity of crushed aggregate base course in the state of Wisconsin was evaluated in light of the gradational, regional, and source variations. In this project, 37 different aggregate samples are collected from different aggregate origin groups. The grouping is decided based on stiffness and durability parameters recorded in the Wisconsin DOT database of approved aggregate sources.

The different aggregate specimens were tested for the resilient modulus values. The results revealed that the Carbonate aggregate mineralogy have higher resilient modulus values than Precambrian, and felsic-plutonic ones. In addition, the study showed that the resilient modulus is sensitive to gradation. The study indicates that the change in the resilient modulus does not show specific trends corresponding to the gradation. One of the most important conclusions of this study is that there is no simple and affordable test that can accurately predict the resilient modulus of the base course. The study recommends that more resilient modulus testing to be conducted on the state level to cover a wide range of variability of resilient modulus values for the different mineralogical types.

The base layer thickness and stiffness (which is function of density) are very important parameters in pavement design. To demonstrate this effect, the research team used the MEPDG software to determine the expected life for a typical HMA pavement section while varying the base layer thickness and resilient modulus. The pavement design is conducted on HMA pavement cross section of 8in HMA, and Subgrade of AASHTO classification A-1-a. The thickness and the resilient modulus of the base course were then varied to simulate their influence on the design life of the pavement while keeping the other parameters constant. Figure 1shows the interaction between the resilient modulus and the layer thickness. Figure 1 demonstrates that the pavement life is more sensitive to the base stiffness than the layer thickness. In fact there is no noticeable difference between the pavement lives for the 16″ layer compared with the 20″ layer. The trend shown in Figure 1 further highlights the importance of incorporating the base stiffness (which is function of base density) as a specification criterion for developing a performance based specification.

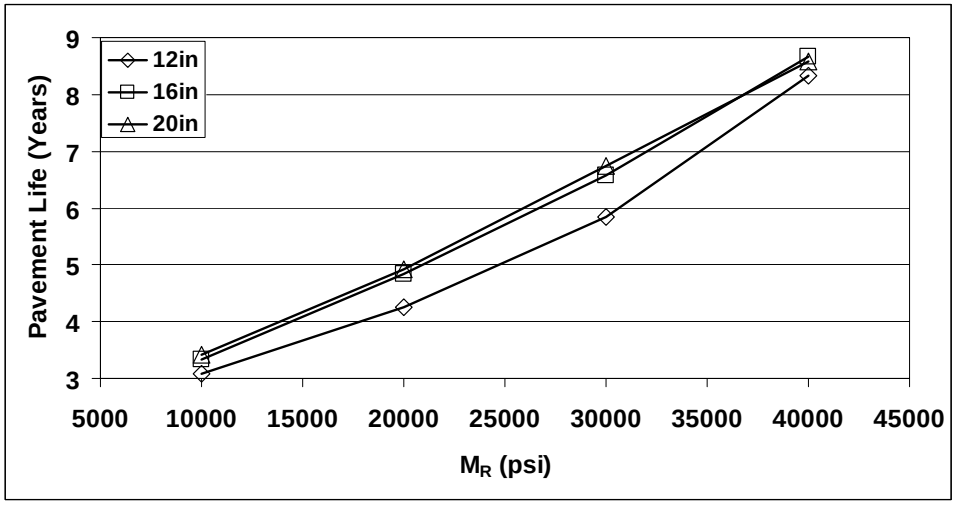


Figure 1: Effect of base layer thickness and resilient modulus on HMAC pavement life as obtained from MEPDG software analysis.

b. Research Approach

Work Plan

The research team will conduct following tasks:

Task 1: Obtain State Of-The -Art/Practice Information On Compaction of Base Aggregates and Specification Criteria.

The research team will conduct a comprehensive literature search and review to obtain information and data on compaction of base aggregate and specification criteria. The literature review will be conducted on two levels: national level and state (local) level. Publications (technical papers, reports, thesis, project documents, project diaries, state highway agencies standard specifications, etc.) on compaction of base aggregate and specification criteria will be collected, reviewed, analyzed and synthesized. Collected information and data pertaining to the standard specifications for base aggregate construction/compaction that includes but not limited to:

1. type of compaction method used (observation based, performance based)
2. aggregate base compaction requirements/criteria (base material characteristics/properties (such as gradation and CBR), lift thickness, compaction equipment, etc.)
3. methods of quantifying/measuring criteria (Standard Proctor, Modified Proctor, Dynamic Cone Penetration, Geogage, FWD, LDW,etc.)
4. criteria used for quality control and quality assurance of compaction (e.g., 95% of dry density)
5. acceptance/rejection versus payment (e.g., below 90% of dry density reduced payment or rejection)

The research team will conduct a survey on the practices/specifications of state highway agencies and will mail/distribute this survey to all 50 state highway agencies in the country and to state highway agencies in Canada. The survey will be designed by the research team and approved by the TOC (or the project oversight committee) before distribution to assure the benefit of the survey. In addition, the research team will obtain the standard specification for roads and bridges from all state highway agencies in the US and Canada. These specification will be reviewed/synthesized and results will be tabulated for all state agencies to achieve on the objectives of the research (i.e. to help WisDOT make a decision for specification transition) Most of these specifications are available online; for example, the aggregate base standard specifications for Illinois can be obtained from:

http://www.dot.state.il.us/desenv/pdfspec2002/sec300.pdf

The research team collected and summarized base materials construction specifications in Midwest. As presented in Table 1, most of Midwest state DOTs use performance based specifications.

Table 1: Midwestern state base course compaction specifications

State	Performance based	Compaction limits	Test Method
Minnesota	Yes	1- Not less than 100% of maximum density	AASHTO T19
		2- No further consolidation	NA
		3- Dynamic Cone Penatrometer Index ≤ 10mm	MnDot method 2211.3C3
Illinois		1- Not less than 100% of maximum density	AASHTO T99
Indiana		1- Not less than 100% of maximum density	AASHTO T99
Ohio		1- Not less than 98% of maximum density	Ohio test method 1015.05
Michigan		1- Not less than 98% of unit wt. at Moisture content not greater than optimum	Michigan test method 123
Iowa	No	1- No further consolidation observed	NA
Wisconsin		1- No further consolidation observed	NA

On the local (state) level, the research team will review WHRP report # 0092-02-01: Determination of Influences on Support Strength of Crushed Aggregate Base Course due to Gradational, Regional, and Source Variations. This report will provide the research team with good information pertaining to the sources of base aggregates in Wisconsin such their physical characteristics, material type, source lithilogy and regional factors influence the resilient modulus of these aggregates. The research team will also provide a critical analysis of how the results of this report (# 0092-02-01) may influence the MEPD since resilient modulus testing was conducted using SHRP P46 protocol while the current resilient modulus testing is the AASHTO T307.

In addition, the research team will design and distribute a survey on practices/problems encountered in base aggregate construction in Wisconsin. The survey (after approved by the TOC/POC) will be distributed to engineers/personnel involved with construction of base aggregates. The research team will get the distribution list from WisDOT and WAPA (list includes WisDOT engineers, contractors, and any identified professional who is involved in base aggregate construction). The survey will provide useful information pertaining to the performance of base aggregates during HMA construction and how this performance affects the HMA pavement layer construction and pavement performance. The research teams will also summarize past WisDOT efforts for evaluating the performance properties of base layer materials.

Task 2: Conduct Comprehensive Search of Information/Data and Perform Field and Laboratory Investigation on Past Flexible Pavement Projects on Base Materials

The research team will conduct a comprehensive search of information/data as well as comprehensive field and laboratory investigation on a minimum of 10 flexible pavement projects with base materials that showed variable behavior/performance during construction. These projects will be typical HMA pavement projects in Wisconsin (not special projects). The objective is to thoroughly examine all available historical information/data and gather more information/data (via the field and laboratory testing program) in order to identify why these projects performed the way they did? Details of collecting the information/data through the search and through the field/laboratory investigation are given in the following subtasks:

Subtask 2.1: Develop Database of Past Flexible Pavement Project with Base Materials of Variable Performance

The research team will develop a database of a minimum of 10 WisDOT construction projects for evaluation of base aggregate stiffness variability. Projects will be identified in a coordinated effort with the TOC/POC. As describe by the RFP, the following criterion will be used to identify these past projects: *Projects of flexible pavements constructed over base materials as defined by WisDOT SS 305 and built since 2000*.

Information/data that will help identifying these projects will be collected through:

1. The survey designed in Task 1 for the local (state) level and mailed to/conducted on WisDOT and contractors personnel
2. Review of project diaries for pavement performance data during construction. Diaries will have useful information on the weather, equipment used, notes if base material deformed (base yield under the paver) during HMA layer construction etc.
3. Search WisDOT Pavement Inventory File (PIF) pavement performance data for information/data pertaining to the performance of these projects during construction.

Effort will be made to coordinate the projects used to populate the database with materials used in previous WHRP studies.

Projects identified in Subtask 2.1 will be subjected to comprehensive review to collect information and data pertaining to the performance of base materials during construction. The data/information collected from these projects will provide a good range of base materials variability in terms of compaction and stiffness during the construction of the HMA layer. It is expected that the research team will be able to obtain a minimum of 5 projects with excellent performance of base materials during HMA pavement construction and a minimum of 5 projects with poor performance of base materials.

Subtask 2.2: Conduct Comprehensive Field and Laboratory Testing Program on the Identified HMA Pavement Projects

The research team will conduct comprehensive field and laboratory testing program on the identified (minimum 10 projects with variable base performance during construction) that includes but not limited to the following:

1. Perform pavement condition survey: For each of the selected projects (minimum 10), three test sections will be identified to perform field testing. The research team will conduct a wind shield survey to determine these three test sections so that they include problem areas (failure zones/areas) as well as good areas. Each test section will be 150 ft long. Detailed visual pavement distress survey will be conducted to quantify various distresses based on type, amount, and severity level. The Pavement Condition Index (PCI) will be then calculated for each section and the mean PCI value for the pavement will be determined. It should be noted that three 150-ft sections will provide enough information to accomplish the objective of this research. If conditions in the field (based on actual observations) require longer sections, the research team will increase the number of sections and the length so that satisfactory level of data is collected. The research team will also determine the Pavement Distress Index (PDI) for the surveyed sections and pavement since this index is used by WisDOT.
2. Perform and analyze FWD testing: The selected test section (contains failure zones/areas) will be subjected to FWD testing in a detailed way that is depicted in Figure 1. FWD tests will be conducted every 10 ft along each section in three different locations as shown in Figure 2. This FWD test plan will provide test data on a "grid" format to evaluate the uniformity of pavement the base layer and other variables. FWD tests will also be conducted every 500 ft along the project (other than the 3 test sections). Analyses will be conducted on the FWD test results using backcalculation with inputs on pavement layers thicknesses (from project plans) to calculate the base layer stiffness modulus, pavement structural number, subgrade modulus, pavement layer deflection, etc. Titi and Rasoulin (2002) used the grid test configuration to evaluate base failure on state highway LA-15 in Sicily Island, Louisiana. Figure 3 shows the depression of newly constructed HMA pavement that is measured in some areas to about 4.5″. Analysis was conducted on FWD and Dynaflect test results using back calculation methods. Figure 4 depicts the pavement surface deflection, subgrade modulus, and structural number. The weak areas are easily identified from the analysis of the FWD and Dynaflect test results. It should be noted that UW-Milwaukee has singed a MOU with WisDOT to use the FWD and the proposed PI has been using the FWD for the pre-overlay project for the last few months.

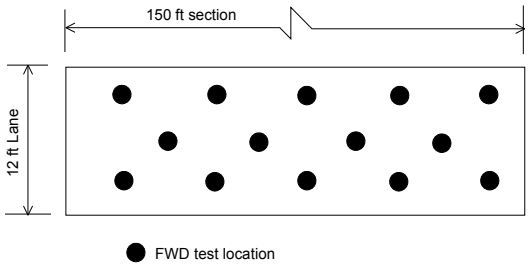
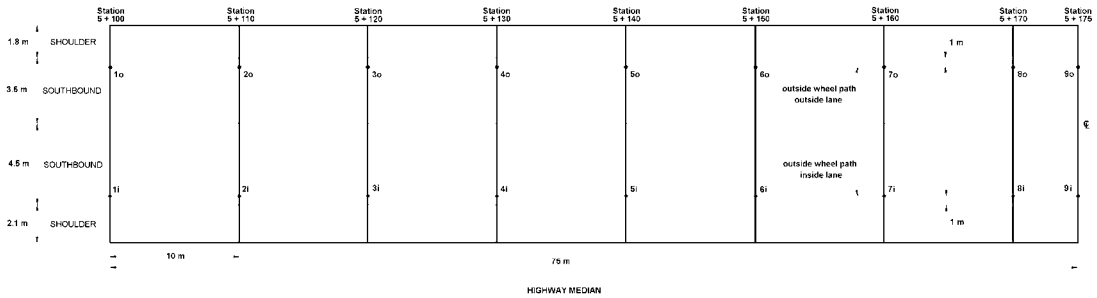
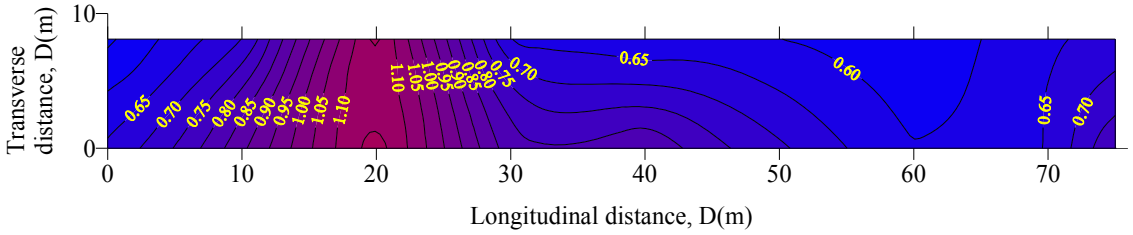


Figure 2: Proposed FWD test plan for pavement sections.

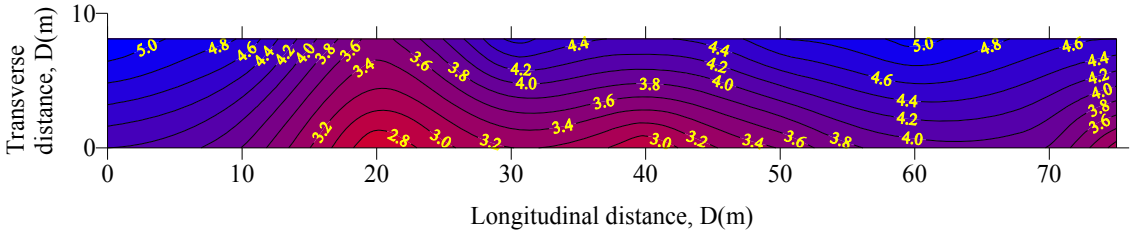
Figure 3: Local failure zone with 4.5 inches of depression, state highway LA-15, Sicily Island, Louisiana (Titi and Rasoulian, 2002).



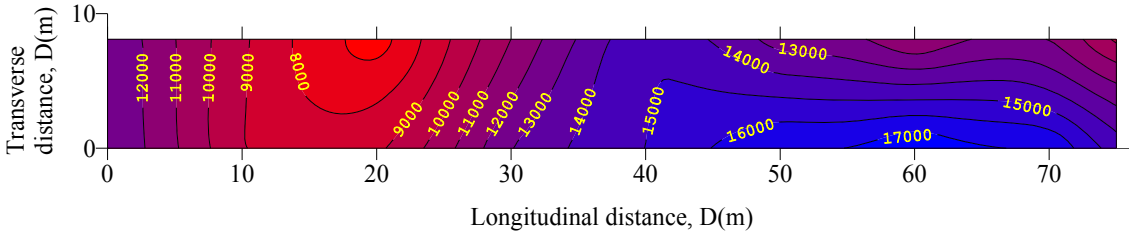
(a) The selected test section with failed and intact pavement areas



(b) Pavement surface deflection



(c) Structural Number (SN) of the investigated pavement section



(d) Subbase stiffness modulus

Figure 4: Analysis of deflection measurements on test sections at state highway LA-15, Sicily Island, Louisiana (Titi and Rasoulian, 2002)

3. Identify and acquire representative base aggregate materials for laboratory tests: base aggregate from quarries that are commonly used in Wisconsin will be identified (from WHRP report # 0092-02-01 as well from information through TOC/ POC/ WAPA/ WisDOT/ Contractors). It is expected to collect a minimum of 10 different base aggregates samples. If base aggregate sources for the projects identified by the database for the field study are known, then those will also be considered for collection and testing. Collected base aggregate will be subjected to comprehensive laboratory tests to determine their maximum dry density, optimum moisture content, grain size distribution (gradation), repeated load triaxial test to determine the resilient modulus according to AASHTO T 307 (AASHTO current required test to obtain resilient modulus of base materials for MEPDG), and all other laboratory tests that will assist the research team in accomplishing the objective of this research. The proposed PI has conducted resilient modulus tests for Wisconsin soils and for base aggregate through 4 different WHRP projects using AASHTO T307. Figure 5 shows the resilient modulus of base aggregate for STH 80 north of highland that was conducted as part of the Intelligent Compaction Project.
4. Establish MEPGD input parameters: based on laboratory test results and collected information, the research team will establish MEPDG input parameters for base aggregate materials. The inputs will be level I parameters since they are directly obtained from resilient modulus test results. The research team will also run comprehensive statistical analysis (similar to the work done by Titi et al. for WHRP – resilient modulus of Wisconsin soils) to provide inputs of level II based on models calibrated from experimental data from resilient modulus tests on base aggregate.

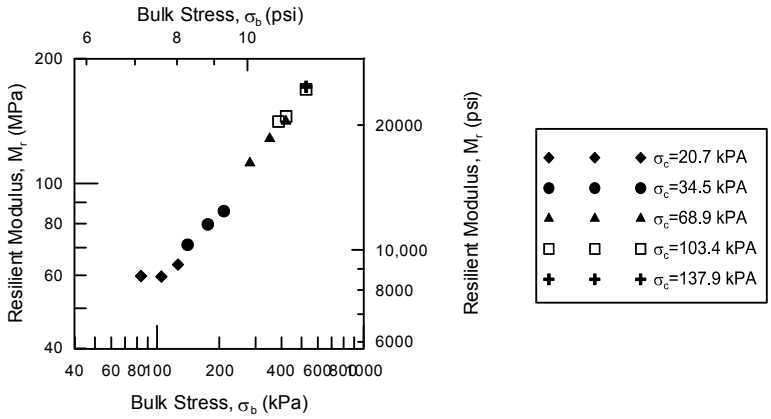


Figure 4: Resilient modulus of base aggregate from STH 80 north of Highland, WI

Task 3: Perform MEPDG sensitivity and cost analysis

Using the developed MEPDG input parameters, the research team will perform sensitivity analysis to investigate the effect of the base aggregate stiffness and properties on the design thickness of HMA pavement layers. Typical HMA pavement sections that are commonly used by WisDOT will be used in the analysis Cost analysis will also be conducted and the benefits will be highlighted.

Task 4: Comprehensive Analysis of Data/Information Collected in Previous Tasks

All data/information collected from all previous tasks including field and laboratory tests will be analyzed and critically evaluated. This will help in achieving the objectives of this research and will help in developing the framework for performance based construction of aggregate bases in WisDOT projects. Analysis of pavement condition survey, FWD tests, collected information from project diaries, laboratory test data, sensitivity analysis using MEPDG, etc. all will help answer the question of the variability of base aggregate performance and how this variability is attributed to construction/compaction of base aggregate.

Task 5: Develop a Framework for a Base Aggregate Specification that Incorporates Compaction Performance Criteria

Based on the results of all previously performed tasks and through consultation with the TOC/POC the research team will develop a framework for performance based construction of aggregate bases in WisDOT projects. Evaluation criteria based on (as an example) relative compaction (% of maximum dry density) as measured by sand cone or nuclear density gage will be proposed. A detailed work plan for comprehensive field study on future projects will be developed to evaluate the proposed specification and criteria on the performance of these projects. Such work plan will lead to validate/modify the proposed specification based on field performance.

Task 6: Reporting and Final Report

The research team will document the effort of the study on a final report in accordance with WHRP requirements. The research team will also provide PowerPoint presentations that include:

- Laboratory and field testing
- Flexible pavement design sensitivity
- Project FWD analysis
- Laboratory and field correlations of resilient modulus

The research team will also deliver in the final report:

- Recommended base aggregate Specification that incorporates compaction performance criteria (incorporating WisDOT's direction related to MEPDG inputs)
- Feasibility recommendation based on engineering principles and costs.

c. Anticipated Research Results and Implementation Plan

The results/findings of this research will lead to development of performance based specifications for base aggregate construction. The new proposed specifications will be evaluated through the framework that will be developed by Task 5 (above). Therefore the specification (if approved by WisDOT) has the potential to be implemented in the following:

- Specifications: SS 301.3.2, 301.3.4.2, 301.3.4.3
- Contract Administration Guidance: CMM Chapter 3
- Facilities Development Manual: 14-10-5

The research team will address the following items:

- Potential changes in practice in WisDOT base aggregate projects
- Benefits to WisDOT in terms of pavement performance and cost savings
- Tools to facilitate implementation of specification by WisDOT

Time Requirement

A project time duration of 12 months (4 quarters) is proposed. The proposed project beginning date is October 1, 2010. Project schedules for different tasks are shown below.

Task	Quarter			
	1	2	3	4
1				
2				
3				
4				
5				
6				#

#denotes final submittal after review comments are incorporated